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AUTHOR Fitzhugh, Robert J.
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ABSTRACT

This paper oriented for new researchers entering the field of CAI research discusses the research experience in this area, outlines some of the important computer requirements of CAI research, and proposes a conservative computer development strategy to meet those requirements. The development of PLATO and TICCIT are described as examples of the preoccupation of early research with the problems of the delivery vehicle--the computer--rather than with the problems of instruction. In considering systems for research in the instructional area, it is suggested that a general-purpose system with manufacturer provided hardware and software may be more appropriate than special-purpose systems because of the need for flexibility and generality in addressing the diversity of instructional issues that remain unresolved. User initiated systems development is a high risk venture that historically has proved to be fraught with opportunities for failure. Ways in which CAI/CMI research requirements can be met with commercially available standard systems are examined, with emphasis on those research requirements that are generally most difficult to satisfy. The passive role of CMI as a management tool to collect, manage, analyze, retrieve, and display student performance data is explained, and factors to be considered in selecting a computer system for CAI research are discussed. (EAC)

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COMPUTER SYSTEM REQUIREMENTS FOR CAI/CMI RESEARCH

Robert J. Fitzhugh

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The Pacific Systems Group
Eugene, Oregon

Paper presented at the 1978 Annual Meeting of the
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Robert J. Fitzhugh

The Pacific Systems Group

Eugene, Oregon

When viewed over a fifteen year period, computer-assisted instruction has exhibited a notable lack of continuity and systematic growth. In the early sixties, CAI attracted interested researchers from the fields of engineering, the behavioral sciences, and education. During this early period, development money was more easily obtained, and CAI research and development began at scattered sites throughout the country. There was enthusiasm and optimism in the promise of CAI and in its potential impact on educational practice. However, by the late sixties, much of this enthusiasm had waned as it came to be realized that the computer offered no easy solutions and certainly not at a cost acceptable to the majority of the nation's schools. The cost of CAI research came under attack as research funds in general became scarce with the escalation of the Vietnam War. Computer-assisted instruction, never a fully accepted discipline, became increasingly more difficult to justify to cost/performance oriented agencies under pressure to demonstrate the immediate relevancy of the research they were funding. In addition, the abandonment by IBM of an active CAI development and marketing effort was a major blow which

cost the field credibility and had more impact than most realize. IBM had a public image as a pragmatic, research-oriented firm willing to invest in R&D with long term promise. The departure from the field of such a firm after making a substantial dollar commitment indicated to many that the promise was not there, certainly not in an acceptable time period. Finally, the decision of the National Science Foundation to fund two major demonstration projects, the PLATO and TICCIT projects, significantly reduced the funds available for other smaller projects underway at universities around the country.

The end result was a quiet, gradual, and wholely undramatic departure from the field by many researchers and research organizations. In fact, many not involved in CAI might have felt that the opposite was occurring because of the publicity and media attention devoted to the large PLATO and TICCIT projects. But, the departure was real and is most apparent in retrospect. Of the many researchers and research organizations that entered the field in the early to mid-sixties, only a few have maintained an active and sustained involvement since that time.

Coupled with this and partly as a result of it, the CAI literature never fully developed nor did it find a home. Although some work was well reported, for example that done at Stanford, the remainder was scattered in the computer science, engineering, psychology, and education literatures, and much was reported solely in working papers and technical reports with limited distribution. Communication among

researchers was sporadic and often informal, frequently following discipline lines. With a few exceptions, no comprehensive overview works were produced that would enable a newcomer to the field to easily assay the state of the art.

This lack of continuity in research experience and the lack of a well developed, accessible CAI literature raises the concern that new researchers entering the field might be unable to fully benefit from the experience of the past. Much of this experience dealt with the development of computer technology appropriate to computer-assisted instruction and often was hard-earned and costly. This paper discusses that experience, outlines some of the more important computer requirements of CAI research, and proposes a conservative computer development strategy to meet those requirements.

A Preoccupation with Computer Technology

Much early CAI research was preoccupied with the problems of the delivery vehicle, the computer, rather than with the problems of instruction. This was due, in part, to the engineering orientation of some researchers but also because the computer problems were real. The computer technology available to the CAI researcher was relatively immature and frequently inappropriate to the application. The resident control programs, or "operating systems," provided by the computer manufacturers were rudimentary and inadequate for many CAI applications. Computer memory was expensive and often limited. The commonly available

terminal was the teletype which many felt was not suitable for instructional use. Only a few programming languages were available beyond assembly language, and most were intended for numeric applications and not for interactive computing.

The problems were particularly severe for those seeking to exploit the newly developed minicomputer which usually came with little or no usable software and with only a limited selection of input-output and auxilliary data storage devices. This last limitation often forced the CAI researcher to develop an inhouse electronics capability to connect the computer to input-output devices produced by other manufacturers. This process of "interfacing," using the components available at the time, often involved the development of substantial amounts of homegrown electronics. Coupled with homegrown programming, or "software," the development of the computer system was often the dominant activity in the project. Although this was less true of those who used the IBM CAI systems, many of the early CAI projects found themselves reluctantly devoting a majority of their resources, money, and talent to solving the problems of the computer system.

In retrospect, it would be easiest to point to the naivete and lack of computer experience of the CAI researcher as the source of the problem. But, in truth, the naivete should be traced to the computer profession itself which promised more than it could deliver. Few applications in any field escaped unscathed, and rare was the innovative computer project that was completed on time and within budget.

CAI was no exception and was largely preoccupied with the problems of implementing and delivering instruction and less so with the question of what instruction to deliver. There was wide interest in programming languages specially designed for lesson writing, and a number were developed. The most widely used was "COURSEWRITER" developed by IBM. Implied in much of this interest was the notion that the major obstacle to effective computer-based instruction was an inadequate computer system and that effective instruction would result if the problems of programming languages and student terminals were solved. It was fashionable to rail against the constraints of COURSEWRITER and the teletype, and implementation problems frequently dominated conversations among CAI developers.

Of course, this characterization is an overstatement. Many researchers were addressing the problems of instruction. However, the feeling was widespread that computer constraints, including cost, were largely responsible for the lack of success of CAI. This attitude was clearly reflected in the decision by NSF to concentrate R&D dollars on the large PLATO and TICCIT projects. Both projects, particularly the PLATO project, had a heavy computer orientation with the objective of developing a more suitable delivery vehicle at a more acceptable cost. Instructional questions were almost entirely ignored in the early PLATO proposals which focused on student terminal capability and cost. In large part, the explicit PLATO intention was to rely upon innovative, self-trained lesson designers who would emerge from the many faculty and staff exposed to the system. The TICCIT proposal did devote attention

to the nature of the instruction to be delivered, but again, much of the emphasis was on the production and packaging of CAI lessons using an assembly line approach to reduce cost and increase productivity.

The ultimate success or failure of these projects has been difficult to assess although many in the computer community regard the PLATO system as an outstanding technical success when viewed as a pure computer system. The important point here is that both projects were an expression of the belief that CAI was being inhibited primarily by computer system constraints and that effective instruction would result when these constraints were relaxed. Unquestionably, there is a certain degree of truth to this since many early systems imposed a variety of arbitrary constraints on the lesson designer and were extremely awkward to use. However, it now seems clear that the mere relaxation of the computer constraints, as has occurred to some extent in the PLATO project, solves only part of the problem. Once an appropriate delivery vehicle is in place, the problem of what to deliver and how remains. The preoccupation with the development of computer systems to deliver instruction may have masked a more significant problem that may be more resistant to solution. In spite of advances in computer technology, the lesson design process remains an art, and the quality of CAI instruction is almost totally dependent on the personal skill, insight, and intuition of the individual lesson designer. Of course, the problem is not with artful intuition itself,

but with the fact that few are blessed with it.

The computer exacerbates this deficiency because of its need to be programmed in explicit, precise terms. It can perform any logical operation that can be precisely stated, and it can remember all that it has done and all that it has "seen" in the form of input from external devices connected to it. Those familiar with the computer sense that it has the potential to provide instruction especially well adapted to the needs of the individual if it were possible to assess those needs using the information available to the computer and precisely state an appropriate instructional response. Therein lies the problem. The lesson designer seeking to make the computer more than simply an expensive page turner, a common criticism of much CAI, must now identify procedures to acquire instructionally useful information about the individual learner and devise explicit strategies to address those needs.

There is nothing unique about this. The good teacher does it all the time. But, the computer demands that these tasks that the human teacher performs intuitively now be well enough understood to be precisely stated in logical terms. The good teacher remembers what the student has done in the past and uses this information diagnostically to devise new instruction which is appropriate to the individual's needs of the moment. The computer has much the same capability. Whereas the teacher benefits from much richer "input" from a multiplicity of sources, the computer's recall is perfect.

If asked to do so, it could replicate an interaction with a student no matter how long ago it occurred. But, a mechnical recitation of an earlier interaction is of little use. The trick is to know what information is of diagnostic value so that this information can be put to use in guiding future instruction. Presuming that it is possible to answer this question to some degree of satisfaction, the question remains of how this information can be acquired and to what use it should be put.

These are some of the many instructional questions that the lesson designer must answer if the unique powers of the computer are to be fully exploited. It is naive to believe that any of these questions will be fully answered soon. What is needed is sustained research on these and related questions leading to a science of instruction that can serve to refine and augment the intuition of the lesson designer. It is the immaturity of this science that stands as the major obstacle today to effective computer-based instruction.

Computer Systems for CAI/CMI Research

An Argument for Commercially Available, General-Purpose Systems

As has been discussed, many of the early CAI projects devoted a large share of their resources to the development of computer facilities specially designed for computer-assisted instruction. This involved special hardware, such as student terminals, and

special software, such as authoring languages and operating systems. In retrospect, much of this work can be considered valuable but premature in light of the many instructional questions that remained unanswered.

The objective of much of this development work was to facilitate and speed the production of CAI lessons or to develop computer systems that were especially efficient in the delivery of CAI. However, the development of systems specific to CAI inevitably required decisions to be made about the nature of the instruction to be delivered. The efficiency of these special-purpose systems was obtained by eliminating features that were presumed to be unnecessary for the application. Unfortunately, these assumptions were occasionally faulty, and the cost of this efficiency in lesson development and delivery was a loss in research flexibility. Although lesson production might be facilitated, the lesson designer was faced with a variety of constraints on answer processing, data collection, and the like. This is possibly best illustrated by the early authoring languages which frequently underwent an endless series of enhancements and additions in an attempt to relax constraints and to add new features.

For this reason and because of the diversity of the instructional issues that remain unresolved, it is important that any research computer system retain as much flexibility and generality as possible. A general-purpose system with manufacturer provided hardware and software may be most appropriate for the research facility addressing

instructional questions. The quest for special purpose languages and operating systems can easily sidetrack a research effort for years and drain away resources that might be better spent on instructional experimentation and research. The computer manufacturers, particularly the minicomputer manufacturers, have been increasingly sensitive to the needs of the laboratory researcher. Systems are now available that can be used in a variety of research settings with few or no modifications required. Features missing from earlier systems which often motivated researchers to develop homegrown software systems, such as the ability to accurately sequence and time events, are now supported in some standard software. Languages such as BASIC are widely available and understood and, although not ideal, can be used to program nearly any imaginable prototype or experimental CAI lesson. The student terminal problem remains, although more powerful computer terminals are becoming commercially available including PLATO terminals.

In addition to the question of research flexibility, it should be stressed that homegrown systems development is a high risk venture that historically has proved to be fraught with opportunities for failure. The researcher who views the computer as only a vehicle for research would be wise to buy off-the-shelf whenever possible and to resist the temptation to initiate major computer development projects regardless of the capabilities of the inhouse computer talent. Also, it is wise to purchase from major vendors and from a single vendor to the greatest extent possible. The exception might

be computer terminals although, again, it is wise to deal with major, established vendors. The computer industry is volatile, and vendor selection should be based in part on an assessment of the likelihood of the vendor remaining in business and providing continued local support and spare parts. Those who lack familiarity with the computer industry should be hesitant to select vendors without expert advice beyond that offered by the inhouse programming talent.

Microcomputers for Research

The microcomputer promises to become the dominant component in our machine technology and will provide a limited "intelligence" to a wide range of mechanical devices in ways not yet foreseen. The research laboratory will also benefit. Microcomputers are already in use in many research applications (Vesonder, Lesgold, & Wolf, 1977), and interest is widespread. CAI and CAI research will be another beneficiary, and for that reason, a few comments on microcomputers and their capabilities are appropriate.

The microcomputer is not fundamentally different from the computers that preceded it. It is far smaller, consumes less power, generates, less heat, and generally operates more slowly than comparable minicomputers although the speed differences are disappearing much to the concern of some minicomputer manufacturers. The most striking difference is cost. Although the microcomputer's compactness and low power requirements make it technically possible to incorporate the microcomputer into nearly any application requiring intelligence,

it is the low cost that makes it economically feasible. There are few differences of importance beyond this. The microcomputer has no logical or performance edge over larger machines, and can be accurately viewed as simply a cheap, slower replacement. However, in practical terms today, there are a number of differences of which the potential laboratory user should be aware.

The microcomputer is part of an emerging and rapidly evolving technology. There are many manufacturers in the field, more will enter, and some will fail and drop out. Product life is short and competition intense. The microcomputer business is volume oriented, favoring large producers, although some of the large concerns now in the field may not be successful ultimately. Ideas and experienced people are routinely stolen as the firms involved jockey for a competitive edge. This rapid change makes it difficult for the small consumer with little or no prior experience to buy with confidence. It is uncertain which firms will survive and which computer architectures will prevail.

In addition, system cost can be deceptive. Microcomputers are touted as being very cheap, and in fact, they are. The central processing unit, usually on a single chip, is remarkably cheap compared with older minicomputers. Because of the low power requirements of most microprocessor packages, power supply costs are also proportionately reduced. However, from this point on, pricing is roughly comparable. The prices of peripherals such as disk storage

units, printers, and terminals are the same regardless of the computer to which they are attached. More important, these prices have not declined as rapidly as central processor prices. As a result, the cost of peripherals is frequently responsible for the majority of total cost in all but the most bare bones system. Finally, the software provided with most microcomputers is limited and often of poor quality. This is not surprising since the major microcomputer manufacturers are component manufacturers with little prior software development experience. Their expertise is in the manufacturing and marketing of hardware, often not to end users, but to other firms that incorporate this hardware into a final product. This tradition prevails in the microcomputer industry, and the majority are sold directly to other manufacturers who incorporate them into a final product such as a microwave oven and who produce all the needed software. In addition, much of the software that is available directly from the manufacturers is "unbundled" and is priced separately from the microcomputer.

To fill this gap between the bare microcomputers produced by many manufacturers and the needs of the small end-user, numerous firms have been formed which package complete systems composed of components from a variety of sources. The packaged home stereo system composed of speakers from one manufacturer, a tuner from another, and so forth, is a direct analogy. These firms often

provide additional software, the language BASIC for example, and provide a system that is immediately usable.

What does all this mean to the CAI researcher? First, projections that show the microcomputer as having great impact in the future on research instrumentation are no doubt accurate. Microcomputers will be used widely in research applications of all kinds, although often not directly, as many will be embedded in other apparatus. One of the more exciting possibilities in CAI is the intelligent student terminal with the intelligence provided by an "onboard" microcomputer which may or may not communicate at various intervals with a larger, remote computer. The additional possibilities are numerous.

However, the CAI researcher today who is interested in research on instructional problems and who views the computer as merely research instrumentation should be aware of the problems and limitations of the microcomputer. As was pointed out, cost can be deceptive. The bare bones system is just that, and without adequate disk storage or high speed output devices is barely usable on a stand alone basis as anything more than an intelligent calculator. The unsettled nature of the industry introduces the risk that any particular system may be quickly outmoded or, worse, unsupported. Finally, the limited and relatively primative software may be the most serious obstacle to effective use. The sophisticated operating systems and program development facilities found on larger systems are, for the most part,

unavailable on microcomputers. Because of this, basic systems software development is often necessary in many applications to make the microcomputer a useful tool. This inevitably introduces all the problems and risks of homegrown systems development discussed earlier. The concern is that the means to the end, the computer technology, might again become the focus of attention and impede research. For those aware of the pitfalls and limitations, the microcomputer can be an appropriate vehicle and a useful research tool. All others should be encouraged to employ more conventional and mature computer technology.

This is a conservative strategy that would be unexciting to most computer system experts eager to exercise their development skills. However, the objective of this strategy is to reduce the probability that research will be impeded by problems with the computer which should be viewed merely as research apparatus and not as an end in itself. The sections that follow will pursue this theme and will discuss the ways in which CAI/CMI research requirements can be met with commercially available "standard" systems. A complete discussion of this topic will not be attempted, and the emphasis will be on those research requirements that are generally most difficult to satisfy. These comments are directed primarily to those new to the field or less familiar with computer technology and who might be faced with the task of acquiring or extending a computer system for CAI/CMI research.

Computer Systems for CMI Research

The use of the computer as a data management tool is commonly called "computer-managed instruction" or CMI. It is a somewhat misleading term since it conveys a sense of computer control that is not typical of most applications refered to as CMI. Most commonly, the computer plays a passive role collecting, managing, analyzing, retrieving, and displaying student performance data. More active roles are possible in which the computer uses the available data to make decisions or to actively assist teachers or others in making decisions.

CMI is a familiar and straightforward use of the computer and is similar to many data management applications in business. Most computer sales people would have no difficulty understanding the requirements. Data are collected, stored, and retrieved with the computer manipulating or analyzing the data at one or more points in the process. A variety of data collection methods are possible and have been tried. Optical scanners and similar devices that directly accept materials used by the student can be used as well as methods requiring human intervention such as the preparation of punched cards or the manual entry of data through a computer terminal. The information may be stored in a raw, dissaggragate form, or it may be manipulated in some fashion prior to storage. A variety of storage methods are possible, and the selection of a method can be based on factors such as the ease of implementation or the extent to which the method facilitates

selective or rapid retrieval. The CMI system might operate in a "real-time" mode collecting and providing data that effectively describe the current state of the process being monitored, or the system might operate in a "batch" mode in which the data base is updated at intervals such as nightly or weekly and is current only to the time of last update. The data might be retrieved on demand or in the form of regular reports produced at predetermined intervals. The format and nature of the data to be retrieved might be predetermined and fixed, or it might be possible for the human inquirer to formulate unique retrieval requests and report formats. Reports which are produced on demand might be made available immediately, after a short interval of several minutes, or after a longer interval of hours, overnight, or longer.

A great variety of CMI systems are possible and have been developed. However, because of the overall similarity of CMI to commercial data management applications, the computer requirements are much the same and can be satisfied in the same way. With the possible exception of specially designed data entry devices, it is difficult to imagine CMI research requiring special purpose equipment that would not be available commercially. The types of computers that are used in commercial data management would also be suitable for most CMI research. These generally have been larger computers that offer preprogrammed data management software tools that are provided by the manufacturer. However, minicomputers are now available which offer comparable software, and

these smaller machines might be used equally as well in a CMI research application.

If the research is predominately CMI, small business oriented systems produced by manufacturers such as DEC, IBM, NCR, Burroughs, and numerous others might be more suitable than the general purpose minicomputer systems often found in laboratories. The important difference between these systems is not hardware, but software. Some of the small business systems offer superior data file management and report generation tools that could be invaluable in a CMI application. If rapid retrieval is required, the ability of a particular system to support more sophisticated data file structures, indexed-sequential files for example, also would be an important consideration when selecting a system.

Because CMI usually does not have the response time requirements often associated with instruction by computer, much CMI research might be done on shared computers of the sort found in many universities and larger research centers. At the very least, it would be possible to explore small prototype CMI systems in this fashion and avoid entirely the costs and headaches of dedicated systems.

The typical CMI data base is not as large as might be expected compared with many commercial data management systems. Those interested in CMI research should not be mislead into assuming that vast amounts of data storage are required to do research. There are a variety of constraints on data volume, principally the rate of student progress

and the amount of meaningful data that can reasonably be collected about any one student. The data volume may appear large to those not familiar with business data management applications; however, the data volume of the typical CMI system is often modest in comparison.

General statements about data volume per student are of limited use since volume is highly dependent on the level of detail of the information acquired and the time period represented by the data. An early CMI effort (Cooley & Glaser, 1969) found 4000 characters of on-line data storage per student to be adequate in an experimental system with elementary level students. Recently, in one of the more elaborate and ambitious CMI systems developed to date (Wang & Fitzhugh, 1977), 15,000,000 characters of storage were used to describe the curricula in use and the activities for one year of 50 elementary students. In this prototype system, the curriculum descriptions accounted for over two-thirds of the total data volume. Some of this information as well as the more dated student performance information could have been shifted to off-line storage if on-line space had been at a premium. Although this data volume may appear large, modern disk storage technology now makes available disk drives with a capacity of several hundred million characters per unit. These and smaller, less expensive devices may be as readily connected to the minicomputer as to the large super computer.

Finally, because of the similarity of CMI to business data management, the program design and programming talent required is much the

same. The typical scientific programmer found in many research laboratories often lacks data management experience, and those constructing production CMI systems are advised to seek out experienced help. The complexity of data management and business applications in general is often underestimated by the research oriented computer programmer.

Computer Systems for CAI Research

The principal characteristic of most computer-assisted instruction is that it is interactive with the student engaging in a dialogue with the computer. This characteristic alone is not unique to CAI and is shared by many modern computer applications. CAI is similar to many of these other applications, and the computer requirements are generally the same. However, as will be shown, some CAI research may require certain facilities that are not commonly used in other computing applications and which may not be available on all interactive computer systems.

The selection of a computer system for CAI research should be based on a comparative evaluation of each system's overall performance and not on a comparison of hardware performance characteristics or isolated software features. Computer sales people often stress basic characteristics that can be quantified such as execution speed, memory cycle time, maximum I/O rate, and FORTRAN language compile times. It is important to look past this and assess the extent to which the overall interactive characteristics and capabilities of the particular

computer are appropriate to the planned application. Certain features, for example the timing features to be discussed later, might be deemed essential for some research and would preclude the purchase of any system lacking those features. In general, most of these important features are provided by software, and it is important to remember that the modern computer is primarily a software machine. Unless basic systems software development is planned, most of the fundamental characteristics of the hardware, such as the details of the machine language, are unimportant. It is the basic software of the machine, the operating systems, languages, and utility programs, that make the computer's power accessible. It is this software machine and its performance and capabilities that should be evaluated.

When evaluating a computer system, the demands of the planned application should be well understood and should be compared with the capabilities of the proposed system. In general and as is true of many interactive applications, CAI imposes no particularly severe computational or input/output demands on the computer. There may be exceptions such as CAI involving simulations requiring heavy computation or lessons requiring rapid searches of large data files. However, these tend to be uncommon, and most CAI imposes only a nominal load on the computer. In addition, the memory and data requirements are not unusual although they may vary widely and are dependent on the nature of the instruction to be delivered. It should be pointed out that some CAI programs can be quite large although only a small

portion of the total program may be in use at any moment in time. If large programs are anticipated, it may be wise to select a system that supports program overlays or which automatically manages memory in such a way as to permit large programs to operate in a smaller amount of real memory. Again, this is not an unusual requirement and is common to many computing applications other than CAI.

However, there are several factors which are of greater importance in CAI than in other similar uses of the computer. Because CAI is interactive and is directed to a population that is not composed of computer experts, the responsiveness of the computer, the characteristics of the terminal device, and the rules of interaction, or "protocols," that are built into the particular computer system are all important. Finally, some CAI research can impose timing requirements that may be difficult to satisfy on commercially available systems as well as the need to connect unusual laboratory apparatus to the computer.

Responsiveness

Responsiveness is simply a measure of the rapidity with which the computer can respond to human input. It is an important factor in all interactive systems since mental efficiency does not decline linearly as response time increases, but rather drops dramatically when delays exceed certain thresholds (Miller, 1968). In most interactive applications, delays beyond two seconds tend to destroy the continuity of a dialogue and are especially disruptive when the individual is required

to retain substantial information in short term memory for the duration of the interaction. Delays greater than 10 seconds are usually not tolerable if the dialogue is lengthy.

Responsiveness is not a primary characteristic of the computer but is an outgrowth of the way it is employed. On a time-shared computer supporting many simultaneous dialogues, responsiveness normally degrades as the number of simultaneous users increases. Consequently, a large shared system such as is found at many universities might not be an appropriate vehicle for CAI research in which responsiveness or close control over variability in responsiveness are felt to be important. It should also be remembered that on shared systems, the response delays may vary depending on the activity of the moment. The average response time statistics provided by many manufacturers of shared systems may be meaningless if the variability is great as it is on some systems. This variability can be troublesome to the researcher since it is unpredictable and often difficult to eliminate statistically.

Responsiveness is also dependent on the amount of computation or data retrieval the computer must perform to respond to the human input. In a simple drill and practice lesson on arithmetic number facts, for example, the computation performed by the computer prior to its response might be insignificant and require no appreciable time. However, if considerable computation is required, or if the computer must search a data base to obtain needed data, these factors might become the principal determinants of responsiveness.

Generally, large shared systems that are heavily used are not able to perform extensive computation or data base searching and maintain their responsiveness. Research on CAI of this sort might be best done on a dedicated system or a public shared system that is underused or which can guarantee that selected users will receive a measured share of the computing power regardless of the total load. However, since most CAI involves very little computation or data base searching, much useful research might be done on large, shared systems that are becoming increasingly common at universities and elsewhere.

Terminal Characteristics

Although the age of the teletype appears mercifully over or nearly so, commercially available terminals of moderate price remain relatively unidimensional. The keyboard layout is typically that of the typewriter, and responses from the computer are either printed on paper or are displayed on a screen. Print speed is commonly limited to 30 characters per second with a fair to poor print quality. Further, the TV-like display terminals of moderate price ($1000-2500) can usually display only alphanumeric characters although some also have a rudimentary line drawing capability. Generally, terminals in this price range cannot generate complex line drawings or show objects in motion. Display speed can range up to nearly 1000 characters per second; however, terminals that are remote from the computer and are connected to it by telephone are restricted to 30 characters per second unless costly

telephone equipment is added.

These terminal characteristics are constraining in several ways. The speed limitation generally precludes the display of moderate to large amounts of text. The ability to display only alphanumeric characters is limiting with young children and is compounded by the lack of computer controlled audio. This lack of audio has troubled CAI developers since the beginning, and a variety of experimental audio units have been developed and tried. The commercially available speech synthesizers that electronically generate sounds that can be concatenated into a semblance of human speech are relatively inexpensive although the speech produced is often barely intelligible. Systems that operate off a prerecorded word and phrase base produce satisfactory speech although the units are expensive. The Periphonics Corporation produces one of the better units of this type which would be suitable for limited use in a research environment. Mechanical units that generate speech at the terminal site, such as the PLATO audio unit, could also be used although reliability problems should be expected as is true of most mechanical devices.

In general, the computer controlled audio field is not well developed, and the researcher requiring audio should seek the best interim solution that will allow the planned research to be undertaken. Unless a well staffed and capable electronics development facility is available, this same philosophy should guide all student terminal purchase or build decisions. Commercially available terminals remain relatively unidimensional

in capability, and the researcher requiring a richer man-machine interface has few alternatives. The commercially available GRAF-PEN does provide a light pen-like input capability at low cost, but other capabilities such as touch-sensitive input, animated displays, text overlays on still or motion pictures, and speech input are not yet available at a moderate or low cost if at all.

The PLATO terminal is an exception and represents a major improvement in student terminal design although the price is double to triple that of the terminals discussed above. A set of special-purpose keys are provided on the keyboard, new characters can be defined for display, and reasonably complex graphics pictures can be displayed and shown in motion. However, to a large extent, the terminal design is integrated with that of the PLATO computer system and is predicated on the availability of a computer able to interact very frequently with each terminal. This ability of the PLATO system to support such a high interaction rate is one of the most impressive technical features of the system and significantly enriches its interactive capabilities. Unfortunately, most commercially available shared computers with many terminals cannot support such frequent interactions, especially the character by character processing the PLATO system performs on student input. Consequently, PLATO terminals operating on other systems lose some of their most attractive features. In spite of this, the terminal is a significant improvement over conventional terminals and might be used very productively in a research environment.

Terminal Protocols

On every computer system designed to communicate with users at computer terminals, there are a set of rules that govern the use of the terminal and how information is entered through it. By and large, these rules are established by the resident control program, or "operating system," in the main computer and not by the computer hardware. This resident control program will usually also provide services that can be evoked through the typing of special commands which may be single characters. For example, a certain key might be used to signal the operating system to ignore the last character typed and another might be used to indicate that the current and partially entered line should be ignored. On some systems, the range of these immediately available services is extensive through the use of specially defined characters and code words. These might enable the user at the terminal to request the time of day, request a report showing who is using the computer at the moment, or abort a computer program the user may be running.

There is no standardization of these rules and commands among computers produced by different manufacturers although there tend to be certain similarities and common conventions. In addition, most systems will not permit the rules of interaction to be altered or all of the special keys and commands to be disabled. This can present a problem with CAI, especially with children, since these commands might be accidently evoked by the unsuspecting student or teacher resulting in a disruption of the lesson.

On some computer systems, the CAI program can examine each character as it is typed. However, on most systems, the CAI program receives an entire line and only "sees" the line when the student terminates the line with a special character such as "return" or "enter." Young students or students who infrequently use the computer often forget to do this. Some systems also permit the user to type even though the computer may be printing on the terminal at the moment. The computer stores these characters until it is finished printing. It then prints the previously entered characters and treats these characters as part or all of the user's response. The experienced non-CAI user can take advantage of this feature by anticipating the response required and entering it even though the computer has not completely printed the message requesting the response. However, a child might inadvertently depress one or more keys while the computer is printing and have those characters treated as part or all of the response. If any of the characters happened to be special command characters, the lesson might be disrupted or even aborted.

There are a number of other potential problems depending upon the characteristics of the particular system. When selecting a general-purpose computer system for CAI use, it is important to examine carefully the rules of terminal use to determine the extent to which they are appropriate to the population of students that will use the system. This is an area where experienced advice can be useful as there can be a variety of hidden pitfalls that may be difficult to foresee.

Event Timing and Response "Time-Outs"

Input-output event timing refers to two potential capabilities of the computer, the capability to accurately record the time when an input-output event occurs and capability to accurately control the duration of selected events. The first capability is commonly used to calculate response latency, the time required for the student or subject to respond to a stimulus event such as a question displayed on a screen. Since the material may not be displayed instantaneously and the subject's response may involve multiple key strokes, the latency interval may be calculated in several ways. Depending upon the display speed and other factors, the latency interval can be assumed to begin at the time the first character is displayed or at the time the last character is displayed. With a multiple character response, the time of the response might be the time of the first character typed, the time of any selected character in the response, or the time of the last character in the response.

Since few applications outside the behavioral sciences require the accurate recording of response latency, many commercially available interactive systems lack this ability. On such systems, a rough measure of response latency usually can be obtained by designing the CAI program to request the time of day from the computer following the stimulus display and immediately after the subject's response. This may be more or less satisfactory depending upon the timing characteristics of the particular computer system and the amount of other work it is doing at

the moment if it is a public shared system. Although this method may introduce a potential error as great as several seconds, this might be adequate for instruction where the intervals are typically lengthy due to the need for the student to read a passage, perform a difficult problem solving task, provide a constructed response, or perform an off-terminal calculation. However, research requiring latency measurements accurate to the millisecond level must be done on a system that includes facilities designed for that purpose. Contrary to the belief of some, this need not be a single-user or special-purpose system. General-purpose time-sharing systems can and have been designed that provide this timing information to an acceptable level of accuracy regardless of the amount of other work the system may be doing at any moment (Fitzhugh & Glaser, 1975; Fitzhugh, 1973).

The ability to accurately control the duration of selected events is another feature that is not commonly found on commercially available shared systems. For example, this feature might be used in CAI research to display material to a subject for a precise, measured interval followed by the erasure or modification of the display screen. If the intervals are relatively short, there are a number of ways this might be done on a general-purpose shared system not designed for this purpose (Lesgold & Fitzhugh, 1977). However, in general, accurate event sequencing is difficult to do on a general-purpose shared system simultaneously supporting a variable number of other users.

With certain forms of instruction, it may be desirable to design

the CAI program to wait for a student response for a measured interval and no longer. If the student fails to respond within the interval, a "time-out" occurs and the program is awakened so that it might take some action such as presenting a prompt or inquiring if the student is having difficulty. In certain research or testing applications, this feature might be used to control pacing by establishing a response interval after which the program proceeds whether or not a response is received. Depending on the design of the system, the CAI program may or may not be able to obtain whatever partial answer the student entered prior to the expiration of the time interval.

Some research may require intervals that are very short or very accurate or both which may not be possible on some systems that purport to offer a time-out capability. A variance of several seconds in the interval may be unimportant in a CAI lesson that employs a time-out interval of several minutes simply to regain control in the event the student experiences undue difficulties or leaves the terminal. However, this would be unacceptable in an experiment in which the subject is allowed only a few seconds to respond. Again, it should be pointed out that it is possible to design a general-purpose, time-shared system that provides accurate intervals regardless of the number of other users on the system or the computing load they may be imposing. However, many of the systems sold today lack this capability, and there is a trend toward the development of intelligent experimental apparatus able to time events locally and transmit this information to the controlling general-purpose computer.

Interfacing Experimental Apparatus

Certain research requires that experimental apparatus other than terminals be connected to the computer. Depending upon experimental needs, this apparatus might include devices such as slide projectors, lights, or special keyboards. The traditional way to connect, or interface, such devices is to develop controlling circuitry which is attached directly to the input/output logic of the computer. This is a direct, electrical connection, and the interface draws its power from power supplies often shared with other devices or the computer itself.

This traditional approach to interfacing has several consequences. When a new device is interfaced, new operating system software is required unless the interface is identical to one already existing. Since laboratory systems tend to evolve over a period of years, standardization of this sort is often difficult to attain. The usual result is a variety of unique interfaces forcing the programmer to deal with a cluttered array of input/output commands that differ for each device. The need to develop and install new operating system software introduces the risk that the existing system might be disrupted due to errors in the new software, mistakes made during installation, or incompatibilities between the old and new software. The direct connection of the interface to the computer introduces a similar risk due to the possibility of errors in the new circuitry, electrical noise from the interface, timing problems resulting from the altered electrical balance, or problems induced in other parts of the computer as a result of the shock or vibrations that

occur during installation.

Unfortunately, the opportunities for error are numerous, and the installation of new devices is often followed by a period of system unreliability as lingering problems are isolated and solved. In addition, the installation and checkout process requires that the computer be taken out of service. On-going experimentation and other use can be seriously disrupted if unanticipated installation problems are encountered and the planned installation schedule cannot be met. Finally, the addition of new hardware and software increases the complexity of the computer system making maintenance and proper documentation more difficult.

Most of these problems can be eliminated by using a character oriented apparatus controller that masks idiosyncratic device characteristics. The apparatus controller makes the experimental apparatus appear as if it is a terminal and allows it to communicate with the computer over a standard terminal line. No special operating system software is required. The apparatus appears to accept and generate alphanumeric characters and is indistinguishable from a conventional terminal to the computer. The result is an orderly and systematic "virtual" input/output structure that is not cluttered with unusual input/output commands. Since conventional ASCII character records are used to communicate with the apparatus controller, laboratory experimentation programs can be written in higher level languages such as BASIC or FORTRAN. The input/output structure of the operating system remains uniform, and these languages do not have to be modified as new devices are added or existing

devices are altered. Most important, the main computer hardware is not modified and, to a large extent, is electrically isolated from the apparatus controller which is typically located in a laboratory room with the apparatus.

At one facility where this approach has been adopted successfully, a number of these apparatus controllers, called Intervening Black Boxes or IBBs, have been developed (Fitzhugh, 1974; Fitzhugh & Glaser, 1975). Some of these units provide a degree of local intelligence and can be instructed to sequence operations contingent upon certain input events as well as record time intervals between selected events. More recent IBBs have been designed to be general purpose, and development work is now underway on an IBB based on a microprocessor.

The principal advantage of the IBB approach is that it insulates the main computer system from the homegrown apparatus and permits unusual devices to be controlled by a standard, unmodified system. In some instances, this may be mandatory if the main computer is a public, shared system or is under a manufacturer's maintenance contract which prohibits local modifications. In addition, the IBB can be used with most all computer systems and can be located outside the laboratory and operated over a dial-up telephone link. CAI research requiring unusual apparatus can be conducted at a school site rather than in a laboratory where it may be difficult to obtain subjects on a regular, long-term basis. On systems supporting multiple terminals, new apparatus controllers can be developed and checked out while the system is operating without interrupting ongoing experimentation.

Conclusion

In spite of the difficulties of the past, there is evidence of a resurgence of interest in computer-based instruction. Much of this interest is in computer-managed instruction. The military has invested substantial sums in CMI systems to improve course effectiveness and reduce costly instruction time. However, there is also growing interest at the grassroots level. Many school districts own or have access to computers which were acquired for administrative use. These districts are now faced with the need to comply with Federal legislation requiring individualized treatment for exceptional students, and many are turning to the computer for assistance in managing the large amounts of data this entails.

The dollars involved are often considerable. In a recent news article (Eugene, Oregon Register-Guard, January 25, 1977), it was reported that the Portland, Oregon school district was requesting approval from the school board to purchase a $2,000,000 computer system. The district's request was based on the claim that the computer was "essential to prevent the district from starving to death for information." This request is not unusual, and many districts now operate large systems or have access to large systems run on a cooperative basis by several districts or local agencies.

This trend provides a partial answer to those critics of CAI who have long questioned whether schools would ever be willing to spend

large sums of money for computers to deliver instruction. The answer is that they have not shown any willingness to do so at all, but they have acquired computers for other purposes. Some of these computers are large administrative systems. Others are small hand-me-down minicomputers for use in a science or math class. But, once present, the systems can be used for other purposes including instruction and student data management. This process of spreading use has occurred in industry, and there is no reason to suspect that it will not occur in education.

However, the availability of a computer for instruction is no assurance that it will be used effectively. With only a few exceptions, the computer-based instructional systems that have been placed in use have been unable to demonstrate their instructional value beyond traditional methods. As has been discussed, this may be the result, in part, of CAI's historic preoccupation with the problems of computer technology which overshadowed the need for sustained research on the underlying instructional questions which must be addressed successfully if CAI is to be effective.

For those wishing to pursue these questions, this paper has stressed the importance of avoiding unnecessary computer system development and has argued for the use of commercially available, general-purpose systems whenever possible. The objective is to retain research flexibility as well as to avoid the problems, costs, and delays that homegrown system development frequently entails. This is not to say that existing instructional systems are inappropriate for research use. The PLATO

system, for example, is well suited for research and offers certain features unavailable elsewhere. However, those who do not have access to such a system or who wish to acquire a dedicated system for research are encouraged to use commercially available systems to the greatest extent possible. This is a conservative strategy, and undoubtedly, there will be research environments to which it does not apply. At the very least, those managing research are urged to adopt an attitude of healthy skepticism and a reluctance to initiate major computer development projects unless it is demonstrated conclusively that the development is essential to the planned research.

The importance and need for good, uninterrupted research on instructional questions is underscored by the fact that it is probably inevitable that computers will find their way into schools given enough time and declining computer costs. The hope is that the development of the computer technology will be coupled with an evolving science of instruction so that CAI systems are developed that are justified because of their extraordinary effectiveness and not merely because they are cheap.

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